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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1221

EXPERIMENTAL FLIGHTS FOR TESTING OF A REACTOR AS AN
EXPEDIENT FOR THE TERMINATION OF DANGEROUS SPINS

By P. Höhler and I. v. Köppen

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EXPERIMENTAL FLIGHTS FOR TESTING OF A REACTOR AS AN
EXPEDIENT FOR THE TERMINATION OF DANGEROUS SPINS*

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ABSTRACT: In the Institute for Flight Mechanics of the DVL a reactor arrangement with a maximum output of 100 kg was investigated as an expedient for the termination of dangerous spins on an airplane of the FW 56 type. The tests were meant to reproduce the influence of a disturbance of the steady spin condition by a pitching or yawing moment.

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 4. PERFORMANCE OF THE TESTS
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 - b. Main Tests
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1. INTRODUCTION

The frequency of accidents in test flights with new models, the spin characteristics of which are unknown, calls for expedients which would support the pilot in terminating that flight condition when dangerous spins, not immediately terminable by control measures, occur. It is not absolutely necessary that the spin stop completely, if only the

*"Versuchsflüge zur Erprobung eines Rückstössers als Hilfsmittel zum Beenden gefährlichen Trudelns." Zentrale für wissenschaftliches Berichtswesen bei der Deutschen Versuchsanstalt für Luftfahrt, E. V., Berlin-Adlershof, Forschungsbericht Nr. 1027, February 25, 1939.

expedient enforces a new steady-spin condition which can be terminated by the customary control movements.

On the whole, a spin may be regarded as dangerous if high angles of attack are attained where the tail surfaces are shielded or the flow at the tail separated, so that the rudder effect is no longer sufficient to disturb the gyroscopic moments responsible for the equilibrium. However, exceptions are known: cases of dangerous steep spins with likewise too small rudder effectiveness, or, inversely, cases of flat spins with extremely high elevator forces which the pilot cannot overcome.

It would best serve the purpose to perform the investigation on an airplane in a dangerous spin. However, since so far no flight tests exist concerning another expedient that would offer 100 percent safety and since the effect of the reactor itself is still unknown, the investigation must, for the time being, be performed on an airplane the steady spin condition of which may be satisfactorily terminated by control movements.

In using the reactor the question arises whether the disturbance should be applied about the Y or Z body axis. The designation "reactor" is not quite justified, since the thrust increase of this arrangement may only last 0.2 to 1 second overall. Nevertheless, it is used here since devices of such type are known in literature under that name.

If the spin is to be terminated by a pitching moment, one starts from the presupposition that the pitch of the spinning airplane increases until subcritical angles of attack are reached where an autorotation is no longer possible. The main fact in favor of this arrangement is its symmetry due to which the same arrangement may be used for left and right spins.

However, experience (particularly on dangerous models) and deliberation show that a termination of spin by a damping of the rotation by means of applied yawing moment is preferable.

The flight measurements described in the present report are for the purpose of eliminating this lack of clarity in the opinions for and against pitching or yawing moment, respectively. Furthermore, the tests are designed to give information about the approximate order of magnitude of the disturbance forces to be applied.

2. SYMBOLS

The symbols used here comply with the most recent flight-mechanical standards. The coupling angles of the three coordinate systems are best

represented by figure 1. The rest of the symbols will be discussed only briefly.

There are:

Ω	(sec ⁻¹)	the resultant angular velocity about the spin axis
$\left. \begin{matrix} \omega_x \\ \omega_y \\ \omega_z \end{matrix} \right\}$	sec ⁻¹	the angular-velocity components fixed in aircraft, positive for rotation to the right
$\left. \begin{matrix} b_x \\ b_y \\ b_z \end{matrix} \right\}$	(m/sec ²)	the components of the resultant air-force acceleration fixed in aircraft, positive in the direction of the positive axes
w_B	(m/sec)	rate of descent
R	(m)	spin radius
v	(m/sec)	resultant velocity
$\lambda = \frac{\Omega b}{2v}$		spin coefficient

The tests are performed in a left spin. Then one has for the signs:

$$\begin{matrix} \omega_x & \omega_y & \omega_z & \Omega \\ <0 & \geq 0 & <0 & <0 \end{matrix}$$

For the coupling angles the pitch is always negative. If the bank becomes negative, it signifies an inward trimming. A positive angle of sideslip corresponds to the inward skidding favorable for spin recovery.

3. TEST METHOD

For the determination of the coupling angles and other important characteristics of the spinning airplane it is necessary to measure the variation with time of the quantities necessary for the evaluation method. For this investigation the determination of the angular-velocity and acceleration components fixed in the aircraft and of the rate of drop

is sufficient. This is done in the simplest manner by means of the "automatic observer" developed by the DVL, a multiple measuring apparatus which combines all instruments and records their indications cinematographically, together with a stop watch, during the tests. For supervision and control of the reactor a manometer is installed which gives, moreover, the moment when the disturbance is setting in.

4. PERFORMANCE OF THE TESTS

a. Installation of the Reactor Arrangement and Preliminary Tests

For reasons of safety the fuel supply equipment of the reactor must be installed behind the seat of the pilot, separated from it by a fire-proof bulkhead. The further masses are distributed over the entire fuselage into the proximity of the tail surfaces, thus influencing the aft position of the center of gravity and, even more, the moments of inertia.

Due to the test installations, an increase of the moments of inertia about the center of gravity of

$$\Delta I_y \approx 25 \text{ m kg sec}^2$$

$$\Delta I_z \approx 25 \text{ m kg sec}^2$$

occurred. The gyroscopic pitching moment,

$$M_K = (I_z - I_x)\omega_z\omega_x$$

which is always positive, increases thereby quite substantially. The increase amounts in this case, for angular velocities assumed constant, to

$$\Delta M_K \approx 45 \text{ vH}$$

The equilibrium of the pitching moments may, therefore, lead to larger angles of attack and hence to flat dangerous spins. For these reasons it was necessary to produce in a second airplane of the FW 56 type, by means of weights which could partly be discarded, the same aft position of the center of gravity and, by stages, the same moment-of-inertia conditions and surface loading. If a dangerous spin appeared for some condition, approximately as much ballast in the form of lead shot could be dropped as to restore again the mass distribution of the former harmless state.

The flight tests with the comparative model up to the same mass distribution of the test carrier resulted in a harmless spin though with small rudder effectiveness.

During the preliminary tests the reactor was used only for production of a yawing moment directed against left spins. The disturbance nozzle was installed below the fuselage, directly in front of the skid. Its distance from the center of gravity of the airplane was ~ 4 m.

The maximum output of the disturbance nozzle in these tests was ~ 45 kg and the maximum thrust of the flight tests did not bring conclusive results. The reactor which was, as already mentioned, installed below the fuselage produced, aside from the desired yawing moment, another moment about the longitudinal axis with unfavorable effect to spin recovery.

Thus the preliminary tests were concluded and the disturbance nozzle was converted to a larger output of ~ 100 kg. A further thrust increase was impossible due to reasons of strength. The reactor was put higher up in the fuselage end so that the lateral thrust force went through the longitudinal axis and the additional undesirable rolling moment was eliminated. With relatively small expenditure of work the disturbance nozzle could be swung about by 90° in order to produce a negative pitching moment.

b. Main Tests

Starting from the preliminary tests, the reactor was at first installed acting about the vertical axis. One started again with a thrust of 20 kg and went up to the maximum output by 20-kg stages.

The disturbance must occur every time under the same circumstances, that is, in each test flight one must wait until the steady condition is attained. In general, a spin is to be regarded as steady when the flight and angular velocities and the accelerations do not show any more variations with time. The airplane with the reactor installed, however, shows, with the present mass distribution, oscillations about all three axes with partly considerable amplitudes which give after a few turns (five at the most) unequivocally a mean value so that one may speak of a pseudo-steady initial state.

While the disturbance was setting in the pilot continued keeping the control surfaces deflected with the spin. In order to maintain the same deflections, stops were provided for the three control surfaces. Although this position of the control surfaces considerably weakened the effect of the reactor it had to be retained for the following reasons:

If the rudder or elevator is moved perhaps to zero position, in which the aileron has been from the beginning, there results in general, depending on the rudder effectiveness, either the ending of the spin or

a new steady condition with smaller pitch. In the case of a steeper initial state one departs from the actual conditions which (as mentioned at the beginning) require the application of an expedient chiefly for a flat spin, and renounces, moreover, the safety guaranteed by the pro-spin control-surface conditions. By movement of the control surfaces every airplane in a harmless spin can be trimmed into an unstable condition, which can be terminated by a minimum disturbance. Such facilitations would falsify the results. In the cases (mentioned at the beginning) with extremely large stick forces which the pilot could not overcome, the control surfaces were partially deflected with the spin complying thereby with the measures undertaken in the investigation for safety.

The disturbance, every time of equal momentum, is of 20 kg thrust for about 22 seconds, thus for 100 kg about 4.5 seconds, and enforces immediately a new steady condition which the pilot terminates only after ending of the thrust performance. A second test series - with the "reactor" in the symmetry plane which now yields pitching moments in the same magnitude - is performed under the same conditions.

The thrust direction of the reactor for both test series can be seen from figure 2.

5. FORMULAS FOR EVALUATION

For every test flight the initial condition and the steady condition appearing during the period of reaction of the disturbance are defined by the characteristics indicated below.

(a) Resultant flight and angular velocity. Spin radius.

$$\Omega = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2}$$

$$R = \frac{1}{\Omega^2} \sqrt{b_x^2 + b_y^2 + b_z^2 - g^2}$$

The accelerations used here are different from the measured ones, since the measuring instruments do not lie at the center of gravity of the airplane; they are corrected according to a method not mentioned here.

$$v = \sqrt{w_s^2 + R^2 \Omega^2}$$

(b) Pitch and bank, compass angle.

$$\sin \vartheta = - \frac{\omega_x}{\Omega}$$

$$\tan \varphi = \frac{\omega_y}{\omega_z}$$

$$\sin \psi = \frac{b_x - g \sin \vartheta}{R\Omega^2 \cos \vartheta}$$

Lastly, the more illustrative banking angle ϕ is determined, which gives the inclination of the transverse axis toward the horizon.

$$\sin \phi = \sin \varphi \cos \vartheta$$

(c) Angle of attack and of sideslip.

$$\sin \beta = - \frac{R\Omega}{v} \left(\sin \vartheta \cos \psi \sin \varphi - \sin \psi \cos \varphi \right) - \frac{w_s}{v} \sin \varphi \cos \vartheta$$

$$\cos \alpha = \frac{R\Omega}{v} \frac{\cos \vartheta \cos \psi}{\cos \beta} - \frac{w_s}{v} \frac{\sin \vartheta}{\cos \beta}$$

Approximately, one may put:

$$\frac{R\Omega}{v} \cos \psi = 0$$

$$\frac{w_s}{v} = 0$$

$$\beta = 0$$

then one obtains

$$\cos \alpha = - \sin \vartheta$$

$$\alpha = 90 - \vartheta$$

The quantities determined according to these formulas are plotted against the moment coefficients of the disturbance referred to the initial condition.

$$C_N = \frac{Sl_D}{gFs}$$

$$C_M = \frac{Sl_D}{gFl}$$

The following symbols signify:

- S thrust of the reactor
- l_D distance of the reactor from the center of gravity
- s semispan
- l mean wing chord

The above relations¹ apply to the perfectly steady condition; thus the mean values of the measured quantities must be inserted.

6. RESULTS

In figures 3 to 6 the measured results of four flights are plotted as examples; two show the influence of the reactor as yawing moment, the two others the disturbance as pitching moment. For both series the effect seems to be the same up to the maximum output of 100 kg. After the application has lasted a short time, after about a half turn, a new steady condition appears in which particularly the considerably smaller amplitudes and frequencies (see figs. 4 and 5) of the oscillations about the three axes fixed in aircraft are noticeable. This phenomenon may stem from the greater stability caused by the disturbance moment.

However, the evaluation shows the effect of the two arrangements to be completely different in its direction. The results are compiled in figures 7 and 8. It is noteworthy that for each test flight the same initial condition was attained. The measured points in the plot signify the steady condition appearing during the disturbance.

¹In a report to be published shortly the formulas and equations used are derived.

It can be seen from the variation of the pitch that the pitch, contrary to expectation, is not influenced by the pitching moment and that this arrangement, therefore, fails completely in the measured range. In addition, the bank shows unfavorable behavior: it causes a lifting of the inner wing and supports the autorotation by the outward skid connected with it. The damping in roll decreases and thus causes the increase of the resultant angular velocity represented in figure 6. As the lift has remained approximately constant and is, on the whole, in equilibrium with the centrifugal force, the spin radius must reduce in proportion to the increasing angular velocity. This effect also becomes clearly manifest in the measurement (fig. 8).

In contrast to the arrangement above, the influence of the yawing moment justifies a prediction of spin recovery in case of a slightly larger thrust. Even if the pitch is increased only slightly, the variation of the bank causes by a further lowering of the inner wing the expected increase of the inward skid. In general, it may be said about the monoplane that autorotation is impossible beyond an inward skid of about 5° .

If a statement has to be made concerning the prospective magnitude of the required sideslip, this can be done only by an extrapolation of the angle of sideslip, which has to be received with the utmost caution. For linear extrapolation a thrust of approximately double magnitude results; actually, however, the inward skid probably increases, with increasing output of the reactor, more strongly than linearly.

SUMMARY

With an airplane of the FW 56 type tests were performed concerning spin recovery by means of a reactor arrangement. The output of the disturbance nozzle, the thrust of which acts upon a lever arm of approximately 4 m, may be increased from 20 to 100 kg. The measurements show that an anti-spin moment about the vertical axis increases, in the measured range, the inward skid about linearly with thrust and could well bring about spin recovery if the output of the reactor were somewhat larger. In contrast, the application as pitching moment proves unfavorable and even results in new steady conditions which are more dangerous than the initial condition.

Translation by Mary L. Mahler
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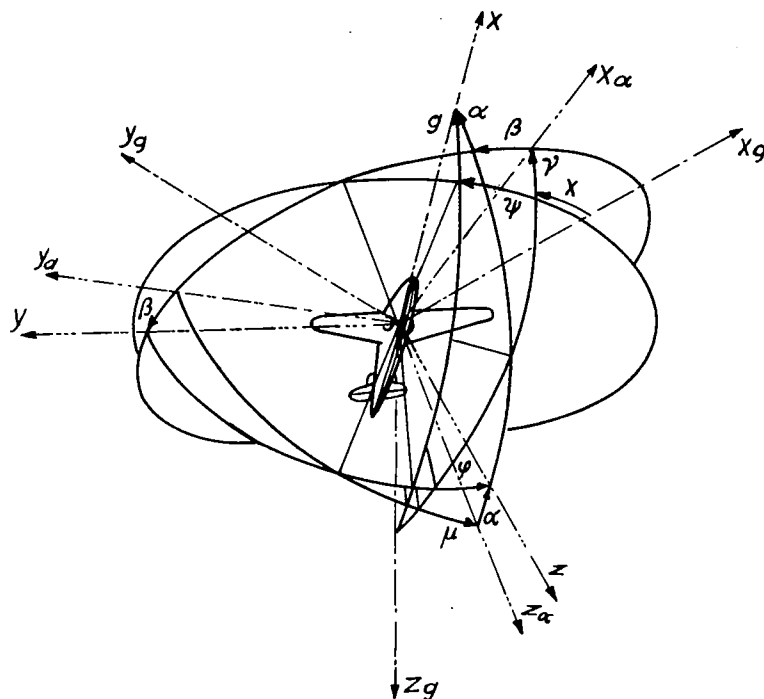


Figure 1.- Axes fixed in aircraft: x, y, z . Axes fixed relative to the flight path: x_a, y_a, z_a . Axes fixed relative to the ground: x_g, y_g, z_g .

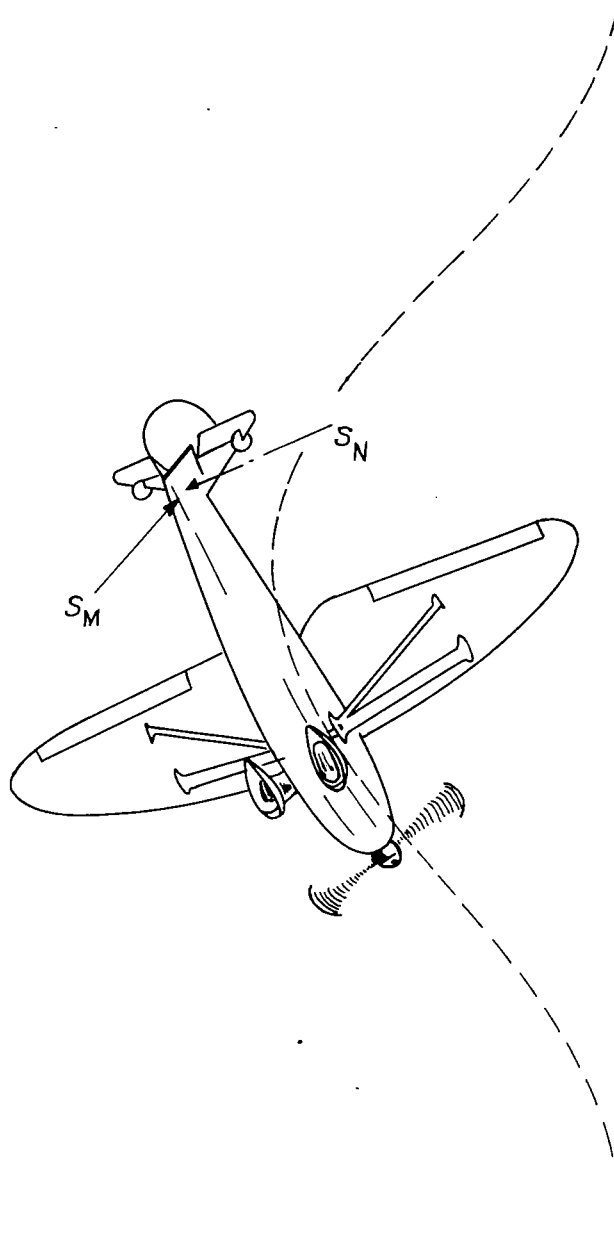


Figure 2.- Thrust directions of the reactor. S_M thrust for production of a pitching moment. S_N thrust for production of a yawing moment.

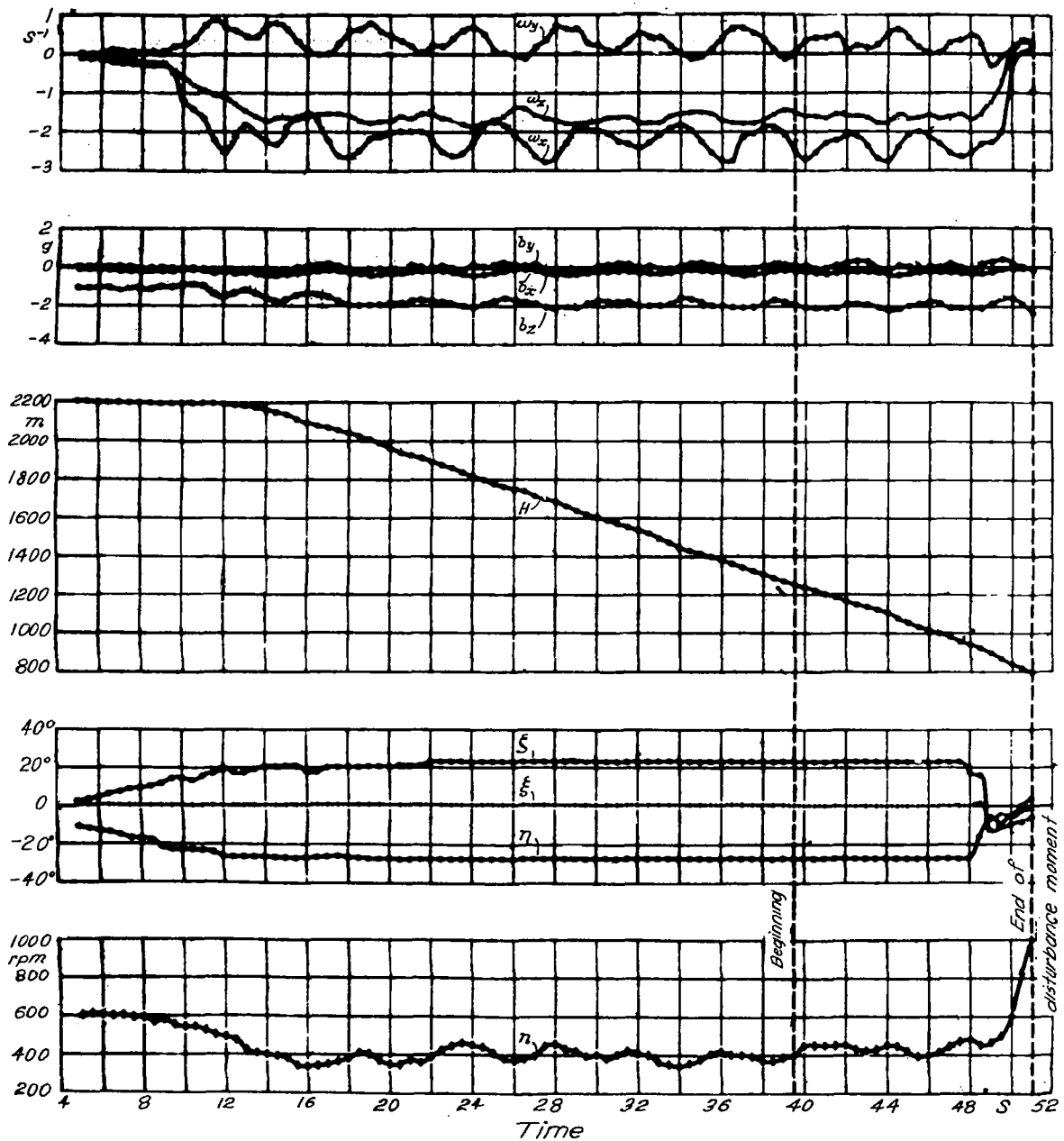


Figure 3.- Flight No. 5 - FW 56 - Pilot: v.Köppen - $S_N = 40$ kg -
November 12, 1938.

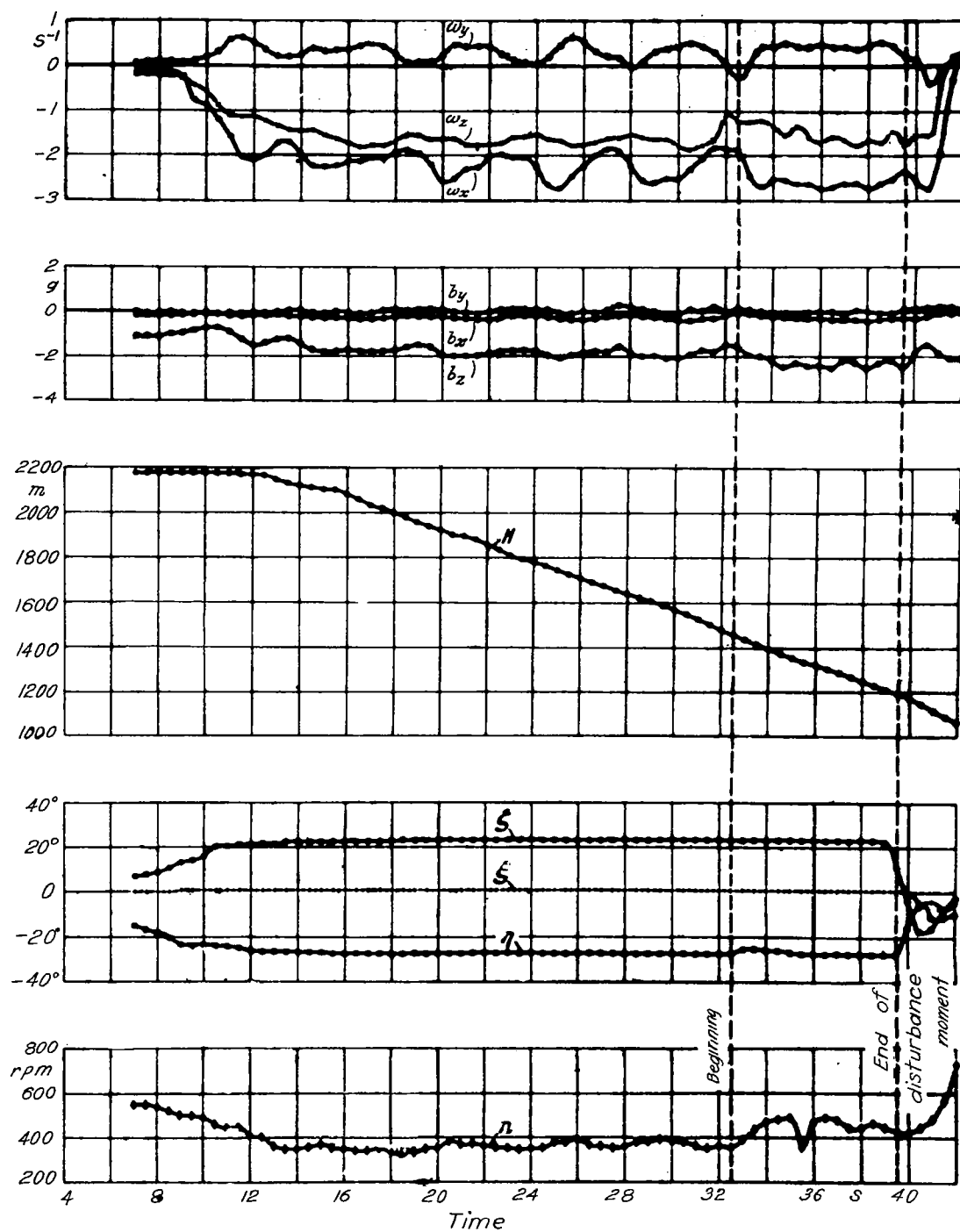


Figure 4.- Flight No. 7 - FW 56 - Pilot: v.Köppen - $S_N = 80$ kg -
December 1, 1938.

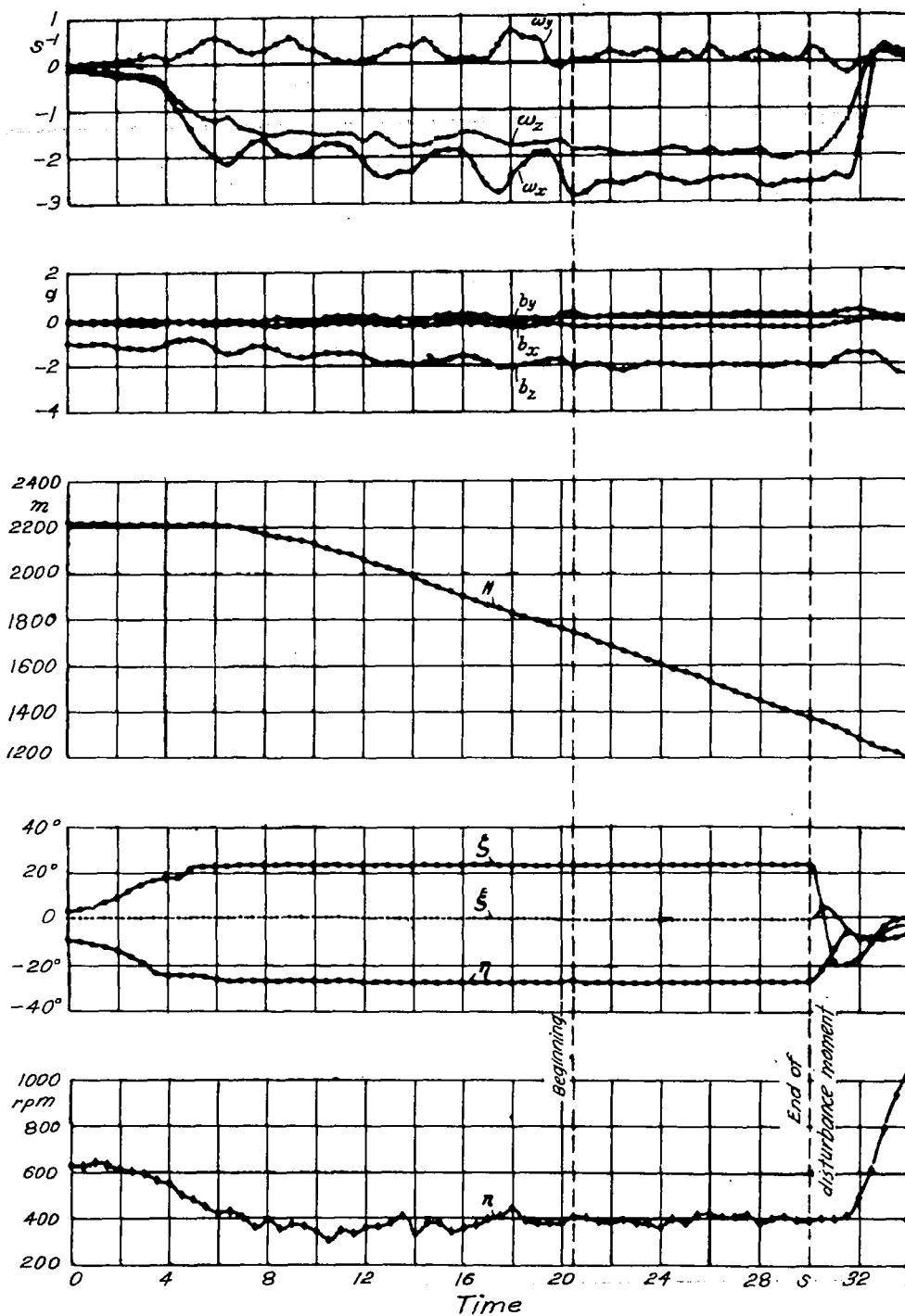


Figure 5.- Flight No. 11 - FW 56 - Pilot: v.Köppen - $S_N = 80$ kg -
December 6, 1938

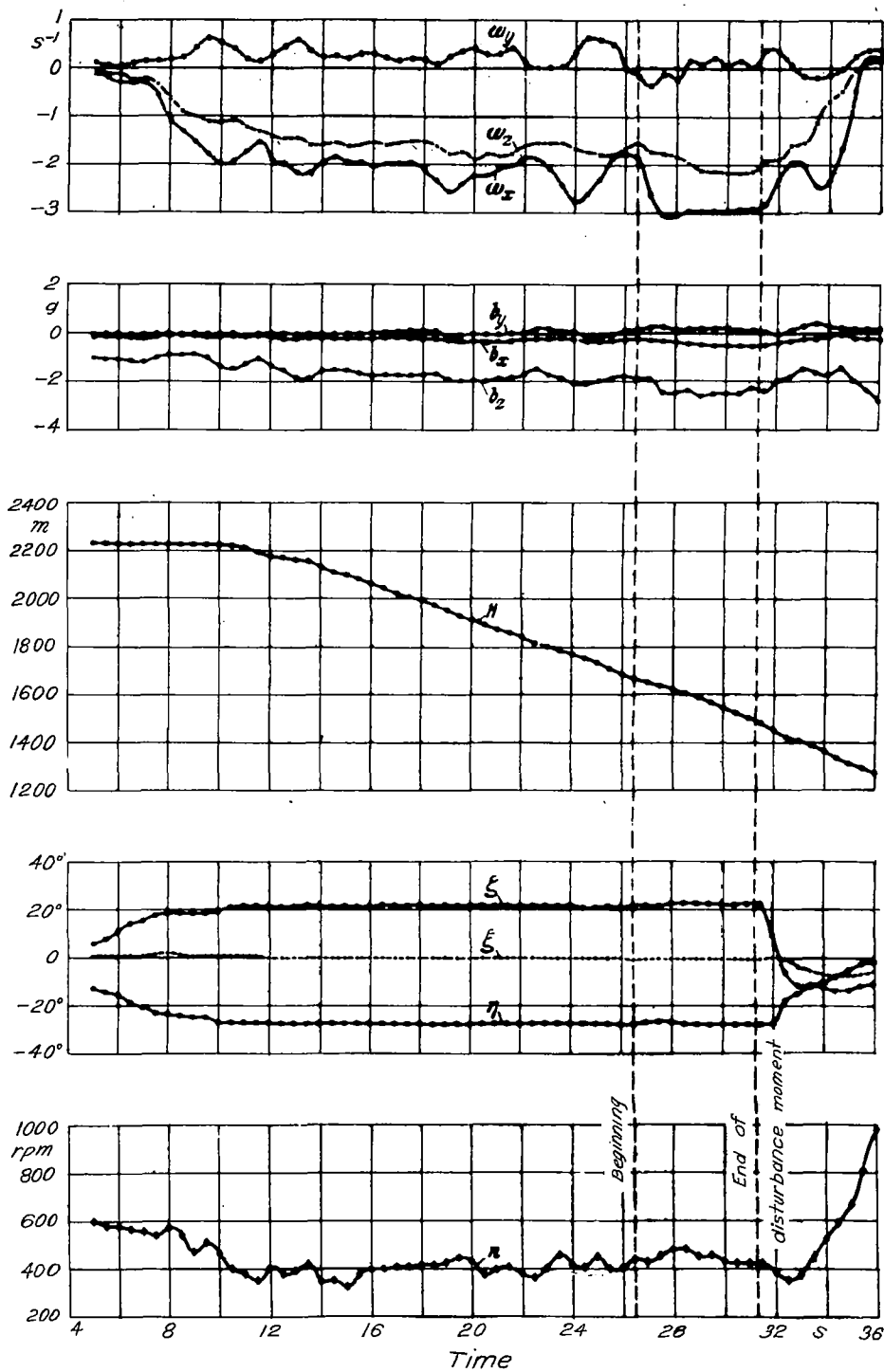


Figure 6.- Flight No. 13 - FW 56 - Pilot: v.Köppen - $S_N = 100$ kg -
December 8, 1938.

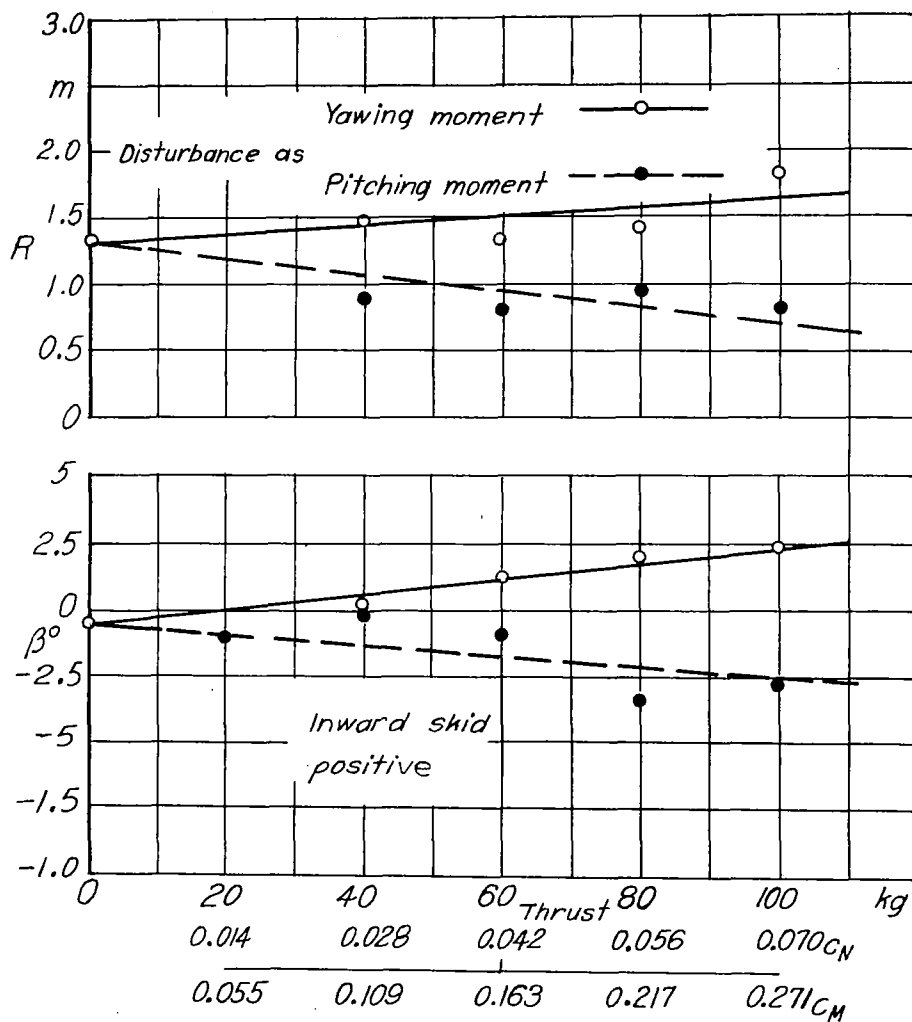


Figure 7.

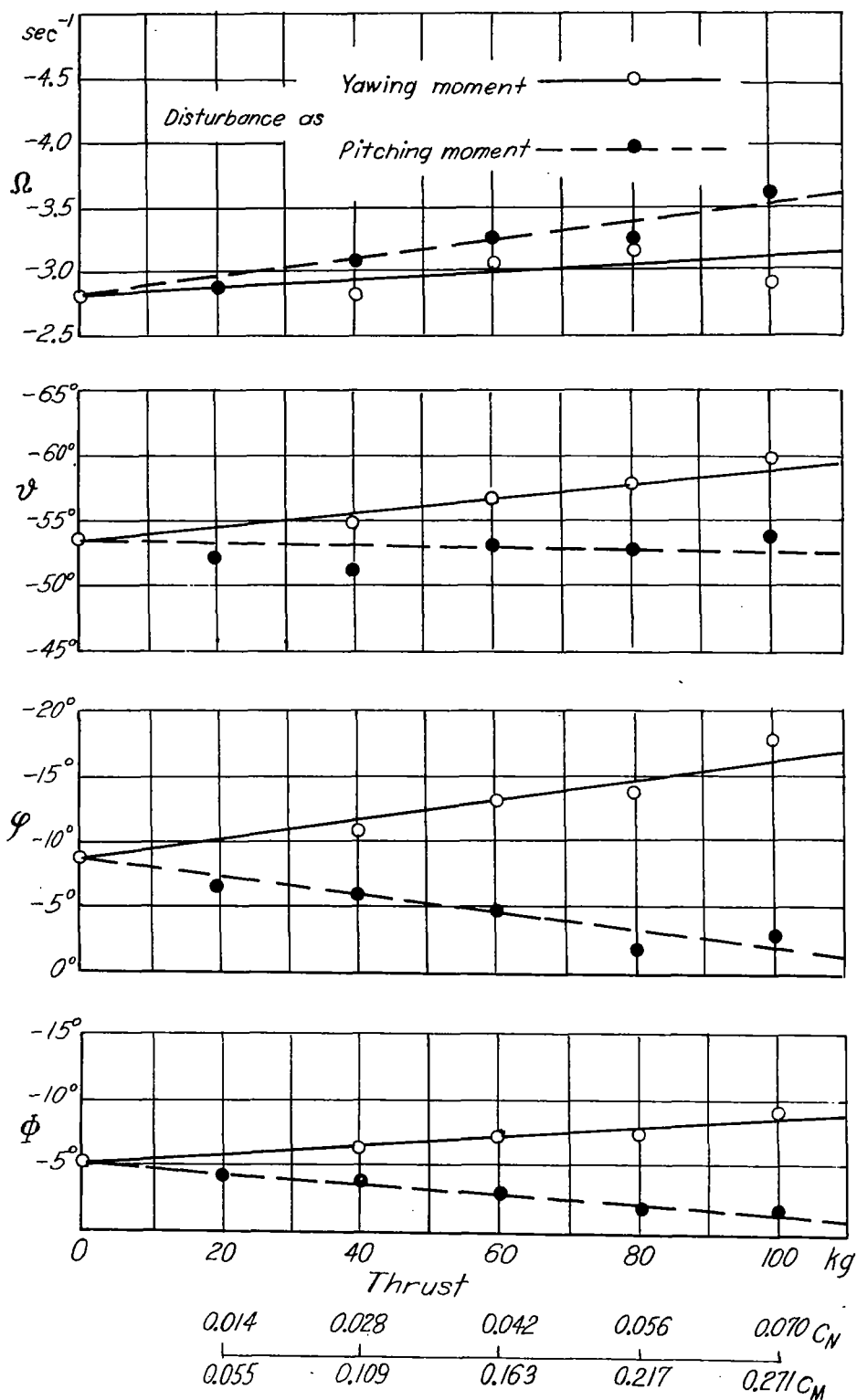


Figure 8.

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